TRANSACTIONS
OF THE
ILLUMINATING ENGINEERING SOCIETY

ST. LOUIS PUBLIC LIBRARY
JUN 11 1944

FOUNDED IN LONDON 1909

INCORPORATED 1930

CONTENTS

Page

Some Eighteenth Century Contributions to Photometry and Illuminating Engineering; Presidential Address by H. Buckley, D.Sc., F.Inst.P. *(Fellow)* - - - - - - 73

Fellowship - - - - - - 88

Filters to Colour-Match Tungsten Filament Lamps with Sodium-Vapour Lamps, by H. G. W. Harding - - - 89

Recent Meetings - - - - 93

Additions to List of Members - - 94

VOLUME IX.—No. 5
MAY, 1944

32 VICTORIA ST
LONDON, SW1

SESSION 1943–1944

THE I.E.S. COUNCIL

President :—H. BUCKLEY, D.Sc., F.Inst.P., F.I.E.S.

Vice-Presidents :—E. STROUD, F.I.E.S.; W. M HAMPTON, Ph.D., B.Sc., F.I.E.S.; H. C. Weston, F.I.E.S.

Members of Council* :—

Elected Members :—

H. S. ALLPRESS, J. B. CARNE, T. CATTEN, H. E. CHASTENEY, W. E. J. DRAKE, S. I. ELLIS, F. S. ETTE, W. HETHERINGTON, J. G. HOLMES, J. W. HOWELL, W. C. HUSTON, H. LINGARD, F. F. MIDDLETON, E. G. PHILLIPS, W. F. POGSON, J. S. PRESTON, E. B. SAWYER, R. P. SAYERS, W. R. STEVENS, J. F. STANLEY, P. CRAWFORD SUGG, DR. J. W. WHITAKER, T. WILKIE, DR. W. D. WRIGHT.

Ex Officio Representatives of Areas :—

Midland Area : W. J. G. DAVEY
Nth.-East. Area : J. M. A. MITCHELL
Nth.-West. Area : J. A. SOMERSET
Nth.-Mid. Area : W. G. THOMPSON
Scottish Area : J. DICKSON
Sth. Wales Area : PROFESSOR P. DAVID JONES
Western Area : J. B. HARRIS

Hon. Treasurer :—
N. V. EVERTON.

Hon. Secretary :—
J. S. DOW.

*In addition, all Past Presidents of the Society are *ex-officio* Members of Council.

Committees

GENERAL PURPOSES COMMITTEE :—Dr. H. Buckley *(President)*, N. V. Everton *(Hon. Treasurer)*, J. S. Dow *(Hon. Secretary)*, R. O. Ackerley, W. J. Jones *(Past-Presidents)*, E. Stroud, Dr. W. M. Hampton *(Vice-Presidents)*, W. J. G. Davey *(Midland Area)*, J. W. Howell *(North Midland Area)*.

PAPERS COMMITTEE :—J. G. Holmes, R. Maxted, J. S. Preston, F. C. Smith, W. R. Stevens, Dr. J. W. Whitaker, Dr. W. D. Wright.

LIGHTING RECONSTRUCTION *(ad hoc)* COMMITTEE :—R. O. Ackerley *(Chairman)*, Dean Chandler, Dr. S. English, Percy Good, W. J. Jones, Dr. C. C. Paterson, F. C. Smith, Dr. J. W. T. Walsh, Sir Duncan Wilson.

AREAS JOINT COMMITTEE :—

Representatives of Areas : *(Midland Area)* W. J. G. Davey, *(North-Eastern Area)* J. M. A. Mitchell, *(North-Western Area)* J. A. Somerset, *(North-Midland Area)* W. G. Thompson, *(Scottish Area)* J. Dickson, *(South Wales Area)* D. C. James, *(Western Area)* J. B. Harris.

Council's representatives : R. O. Ackerley, W. J. Jones, F. C. Smith.

(N.B.—The President, Hon. Secretary, and Hon. Treasurer are *ex-officio* members of all committees.)

SOME EIGHTEENTH-CENTURY CONTRIBUTIONS TO PHOTOMETRY AND ILLUMINATING ENGINEERING

PRESIDENTIAL ADDRESS

By H. BUCKLEY, D.Sc., F.Inst.P. *(Fellow)*

(Presidential Address delivered at the Sessional Meeting held at the Royal Institution, Albemarle Street, London, W.1, on Monday, February 14th, 1944.)

Before commencing my address I must express my thanks to you for the great honour you have conferred upon me by electing me as your President for the present session. I suppose it is natural for each new President to look at the names of the group of very distinguished persons who have preceded him in office. I find that I am the twenty-second President, and in joining this group I do so with feelings of the greatest respect for their achievements.

I am taking as the subject of my address, "Some Eighteenth-Century Contributions to Photometry and Illuminating Engineering." I felt that as I have been connected with photometry for many years my address might well have some bearing on it. I have chosen certain historical aspects partly in view of my own interest in the historical aspects of science, and partly because the historical aspects of photometry do not seem to have been brought to the notice of the Society since 1919. In that year Mr. A. P. Trotter gave us an address on Lambert, and also a paper on "Diffuse Reflection and Transmission," which dealt with Bouguer's and Lambert's work on the subject as well as with his own.

It is really very surprising to find that photometry and illumination have attracted the attention of so many distinguished scientists in the past. Our predecessors include Bouguer; Lambert; Lavoisier, who in 1766, at the age of twenty-three, was awarded a gold medal by the French Royal Academy of Sciences for his essay on the best method of lighting the streets of a large city: Rumford, who did so much in connection with the founding of this Institution; Davy, who discovered the carbon arc and was professor here for many years; Ritchie, who devised the Ritchie photometer and who also later became professor here; Fresnel, who did so much for lighthouse lighting with the Fresnel lens; Foucault, whose photometer was used by Dumas and Regnault in their researches in connection with the street lighting of Paris; Faraday, who introduced the use of the carbon arc in lighthouses and who is this Institution's most illustrious figure; Bunsen, with whose grease spot photometer we are all acquainted; and, finally, if we may bring the list up to modern times, our revered Honorary Member and Past President, Mr. A. P. Trotter, who did so much to establish modern illuminating engineering and illumination photometry as exact sciences.

Time will not permit me to deal with the contributions of so many workers, so I have to confine myself to the attempt to interest you in the work of Bouguer, Lambert, and Rumford, and to show how they opened up avenues of research that we have not yet fully explored.

Pierre Bouguer was born at Croisic, in Lower Brittany, on February 16, 1698. His father was one of the best hydrographers of the time and was Royal Professor of Hydrography at Croisic. Bouguer's father early instructed him in mathematics and navigation, and at the age of thirteen the young Bouguer was sent to the Jesuit College at Vannes, where he astonished all by his wide knowledge. The older Bouguer died in 1713, and in that year, at the age of fifteen, the younger Bouguer succeeded him as Professor of Hydrography.

He devoted himself to physics, astronomy, and particularly to navigation. During his life he three times obtained the prize offered for competition by the Royal Academy of

Sciences for an essay on a subject chosen by the Academy. Thus, in 1727, he obtained the prize for his essay on the best manner of forming and distributing the masts of ships, in 1729 for one on the best method of observing the altitudes of stars at sea, and in 1731 for one on the best manner of observing the variation of

Fig. 1. Pierre Bouguer (1698-1758).

the compass at sea. In 1730 he was promoted to the position of Royal Professor at Le Havre. He later moved to Paris.

His principal claim to fame, however, is based on his measurement of a degree of the meridian near the Equator. This he commenced in 1735, when he was sent by the Academy of Sciences to Peru with la Condamine and others. The work occupied ten years and was published in 1749 as the "Theory of the Figure of the Earth." He here showed that the figure of the earth was that of an oblate spheroid whose polar diameter was less than its equatorial diameter, as predicted by Newton, and not that of a prolate spheroid, as found by Cassini. Bouguer died in Paris on August 15, 1753, at the age of sixty.

His interest to us is due to his work on photometry, which was inspired by a paper presented by M. de Mairan to the Academy in 1721. In this paper it was suggested that to account for the difference between summer and winter temperatures it would be useful to know the ratio of noon sunlight at the two solstices.

On the night of November 23-24, 1725, Bouguer compared the light of the moon when it had an elevation of 66° 11′ with its light when it had an elevation of 19° 16′, these being the elevations of the noon sun at Croisic at the summer and winter solstices respectively. Bouguer chose to make his measurements on the moon from considerations of convenience—the result would, of course, be the same as if the observations had been made on the sun.

The experiment is described in abstract in the "Histoire de l'Academie" for 1726 as follows: "Towards half-past ten in the evening, M. Bouguer received perpendicularly on a piece of white paper the light of the moon when it had an elevation of 19° 16′ and at the same time he received perpendicularly on another piece of paper the light from four candles which were moved nearer or farther from the paper until one judged that their light was equal to that from the moon. To obtain this equality it was necessary to place the candles at 50 ft. from the paper. The next day he repeated the same operation, the moon being at an elevation of 66° 11′, and it was only necessary to place the candles at a distance of 41 ft. Now one knows that the 'force' of a light diminishes inversely as the squares of the distances at which it is received. . . . Thus the force of the moon at an elevation of 66° 11′ being represented by the square of 50 or 2,500, that of the moon at an elevation of 19° 16′ will be represented by the square of 41 or 1,681, which is a ratio of about 3 to 2."

Bouguer also found that when the moon was on the horizon its light was 2,000 times as feeble as when it was at an elevation of 66°.

In addition, an account is given of what came to be regarded as a celebrated experiment—that of determining the ratio of sunlight to moonlight. This is described as follows: "The sun being at an elevation of 31',

M. Bouguer received its light in a dark room through a hole 1 line in diameter to which was applied a concave lens which in virtue of its figure rendered the rays divergent. These rays, received on a paper at 6 ft., where their divergence was 9 in., were, as it is easy to calculate, 11,664 times more dispersed than when they passed through the hole of 1 line.* Taken in this condition their light was equal to that of a candle placed at a distance of 11-3 ft. from a piece of paper which it illuminated. M. Bouguer now caused to pass through the same hole and the same lens the light of the full moon, also at an elevation of 31°. This light was received at such a distance from the lens that it had a divergence of only 8 lines, in consequence it was only enfeebled 64 times. It was now necessary to place the candle at 50 ft. from its paper. From this M. Bouguer has concluded that if he had enfeebled this light as much as he had that from the sun, that is to say 11,664 times, it would have been necessary, in order to equalise the illuminations, to have placed the candle at 675 ft. from the paper. Thus the squares of the numbers 675 and 1 1-3 represent the ratio of the light of the sun to that of the moon. By several other experiments, always made at full moon, M. Bouguer has found that the light of the sun has 300,000 times the force of that of the moon."

These experiments were carried out in July, August, and September, 1725, when the moon was approximately at its mean distance from the earth. The first of these dates is probably that of the first photometric experiment of which we have record.

These investigations, with which Bouguer seems to have started his scientific career, inspired him to investigate several other photometric problems connected with the force of light. It will be noticed, however, that there is no mention in these accounts of anything that bears any resemblance to a photometric instrument.

In 1729 he published his "Essai d'Optique sur la Gradation de la Lumière." He points out that in spite of the work of Alhazen, Snell, Descartes, and Newton there is still a branch of optics which is lacking, viz., that concerned with the measurement of the "force" or "vivacity" of light.

The essay is divided into five parts. The first part deals with methods of

ESSAI

DOPTIQUE.

SUR

LA GRADATION

DE LA LUMIERE.

Par M. BOUGUER, *Professeur Royal en Hydrographie.*

A PARIS,

Chez CLAUDE JOMBERT, ruë S. Jacques, au coin de la ruë des Mathurins, à l'Image Notre-Dame.

M. DCCXXIX.

Avec Approbation & Privilege du Roi.

Fig. 2. Title page of Bouguer's Essai.

measuring the force of light. Bouguer deduces the inverse square law from the fact of rectilinear propagation so that rays from a point source situated at the centre of a series of concentric spherical surfaces spread out over areas which increase as the squares of the distances of the surfaces from their common centre. Consequently the illumination, which is what he means by "force" or "vivacity," varies inversely as the square of the distance. He then points out that this law affords a method of varying the force of light in whatever proportions we wish, as "we have only to receive it at different distances from the luminous body." He also mentions that the inverse square law applies in the case of an optical image; the illumination being inversely as the square of the distance from the focus.

Bouguer recognises that in the comparison of illuminations "one easily sees that one is greater than the other, but one cannot ever distinguish by how much, for of all the ratios it is

*12 lines = 1 inch. 1 line = 0.2256 cm.

only that of equality that one can judge with sufficient exactitude."

In addition to giving a somewhat fuller account of the experiments described to the Academy in 1726, he mentions several others, of which one, concerned with finding out "how much the light is diminished in traversing a certain number of pieces of glass," describes what is apparently the first photometer. Though the essay has several illustrations, there are none at all of his experimental arrangements. The description he gives is as follows: "I took out during the night, to a considerable distance from me and on different sides, a torch and a candle, and making their light enter by two different openings in a kind of box (une espèce de boëte), I received them severally on the back, and I could examine their force because I had contrived a third opening through which I observed." This description certainly seems to be of something which resembles a photometer, but it is quite different in construction from what is usually regarded as Bouguer's photometer, which was first described in 1760, and to which we shall later refer. With this apparatus, using a torch and candle as light sources, he found that the sixteen glasses reduced the light from the torch to 1/240. Similarly, by using the moon as one source he found its light was reduced to 1/254 by passage through the sixteen glasses. If one assumes that Bouguer's candle had a luminous intensity of 1 candle, it is possible to deduce that this last experiment was carried out with an illumination on the photometer of 5×10^{-6} ft.c.!

Bouguer also found that in traversing 9 ft. 7 in. of sea water, which he confined in a wooden trough with glass ends, light was reduced in the ratio of 14 to 5. In the description of this experiment Bouguer points out that if the light source is too close to the water trough, a correction to its distance has to be applied on account of refraction in the water. He gives the well-known expression $(n-1)/n.d.$ for the shortening of path.

The second and third parts deal with the transparency of bodies and the calculation of the transmissions of different thicknesses of transparent bodies. Bouguer shows that in traversing materials whose thicknesses increase in arithmetical progression, the transmissions decrease in geometrical progression, i.e., the logarithms of the transmissions decrease in arithmetical progression. From this he deduced the rule for calculating the transmission for any thickness and the thickness for any transmission given the transmission for a known thickness. Thus, if a known thickness of transparent material has a transmission whose logarithm is x, then n times that thickness will have a transmission whose logarithm is nx.

This enabled him in the last part to solve the problem with which his interest in photometry began, viz., the transmission of the atmosphere. Assuming that the atmosphere were reduced to an equivalent homogeneous atmosphere, then his observations on the moon showed that in traversing the increased thickness of atmosphere due to the change in the elevation of the moon from 66° to 19° the light was reduced in the proportion of 3 to 2. That is to say, this thickness of atmosphere had a transmission of 2/3, whence he deduced that the transmission of the atmosphere in the direction of the zenith was 81.2 %.

As we have said before, the essay was written in 1729. His official duties, however, prevented Bouguer carrying out any more photometric work until about 1756, when he returned to his first love and presented his last scientific paper to the Academy on November 12, 1757. It was entitled "On the Methods of Measuring Light, with Some Applications of These Methods."

A number of photometric experiments are described, mostly in connection with diffusing materials. An excellent account of this work, together with that of Lambert on the same subject, has been given by Mr. Trotter.

About this time he determined to expand and to bring his essay up to date, and prepared what was really a new edition. This was completed in manuscript a few days before his death, on August 15, 1758. His friend, the Abbé de la Caille, a celebrated astronomer, edited the work. It was

published under the auspices of the Academy in 1760 as "Traité d'Optique sur la Gradation de la Lumière."

A considerable portion of the Essay is reproduced word for word in the Treatise, so that there is not a great

TRAITÉ
D'OPTIQUE
SUR LA
GRADATION DE LA LUMIERE.
Ouvrage posthume de M. BOUGUER, de l'Académie Royale des Sciences, &c.
Et publié par M. l'Abbé DE LA CAILLE, de la même Académie, &c.
Pour servir de Suite aux Mémoires de l'Académie Royale des Sciences.
A PARIS,
De l'Imprimerie de H. L. GUERIN & L. F. DELATOUR, rue Saint Jacques, à Saint Thomas d'Aquin.
M. DCC. LX.
AVEC APPROBATION ET PRIVILEGE DU ROI.

Fig. 3. Title page of Bouguer's Traité.

deal of new matter in it. Most of the new matter deals with his work on the reflection of light from polished and mat surfaces. He shows how the reflection from polished metals and from a water surface varies with the angle of incidence, and gives results for water which are not very different from those one calculates from Fresnel's formula. He regarded a mat surface as one which was covered "with numerous little wrinkles (rugosités), or roughnesses (asperités), which, presenting many of their facets on every side, reflect specularly light in all directions. The rays which are lost to one observer become useful to another who is placed in another direction." His object in many of his experiments was to determine the relative number of facets inclined at any angle to the surface.

In the Treatise he gives far more details of his methods, and, in particular, gives illustrations of his various instruments, so that one can, for the first time form some opinion of his equipment. Fig. 4a shows what is usually described as Bouguer's photometer. His description of it is as follows: "One can, in order to receive the two lights which one wishes to compare, make use of a piece of cardboard, ECD, which has a fold at CH, in order that each half of the surface may be exposed perpendicularly to each light. The whole of this cardboard should be black; but it will have two holes of exactly the same size—3 or 4 lines in diameter, to which one will apply oiled paper, or two pieces of glass made equally mat or white by grinding with emery or with grit. . . . I let the two lights fall on these two pieces of paper, and I judge the equality of their force by looking at them from behind or sometimes from in front. A second piece of cardboard, FC, serves as a diaphragm and prevents the two lights from mixing with each other before illuminating the two little surfaces, P and Q. This diaphragm is black on both sides,

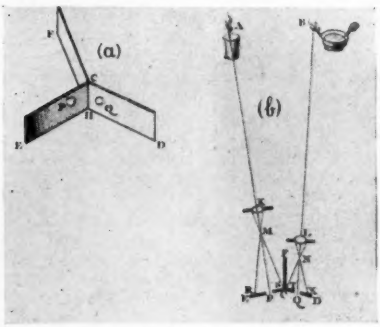


Fig. 4. Bouguer's Photometer.

and is joined to the first cardboard exactly at the ridge which forms the fold."

Bouguer mentions that "this diaphragm is an essential part of the instrument," and that the illustrations do not show diaphragms and curtains to exclude stray light, as when one uses the instrument one realises where they should be placed!

A modification of this photometer is shown in Fig 4b. This modification is used when it is not possible to vary the illumination of the patches P and

Q by moving one or other of the two light sources. In this case, one or other of the lenses is moved and the ratio of the "forces" of two light sources, when the illuminations are reduced to equality, is given by the ratio of $AK^2 \times MP^2$ to $BL^2 \times NQ^2$ the distances MP and NQ being measured from the focused images of the light sources. Alternatively, these distances MP and NQ may be replaced by the diameters RS and TX of the illuminated patches.

As a precaution, Bouguer mentions that he places a small diaphragm at F at right angles to CF to prevent light hitting this diaphragm (CF) obliquely and so being reflected on to P or Q. He also says that the lenses should be mounted in the middle of large surfaces.

As shown in Figs. 4a and 4b, the areas P and Q are somewhat separated. After mentioning that they should be of the same size, he remarks, "the two illuminated images cannot be too near to each other, it is absolutely necessary that one should be able to see them both at a glance, and it will be good if one can make them so that they touch each other. I have nearly always looked at these same images through a hole in another diaphragm which I held at some distance from the eye and which hid every other object from me"

Most of Bouguer's experiments did not involve colour differences, or, if they did, they were carried out at such low illuminations that the colour differences did not cause trouble. All he has to say on heterochromatic photometry is as follows: "The comparison of two lights of different colours in the way we have advised is embarrassing. . . . There is, however, one point at which one of the two lights certainly appears stronger than the other, and another point at which this light certainly appears more feeble, there is, therefore, nothing to be done but to take the mean between the two extremes."

Figs. 5a, and 5b, show two other photometers which Bouguer used for comparing the brightnesses of different parts of the sky or of different parts of the sun's disc.

The former (Fig. 5a), which Bouguer calls a Lucimeter, consists of

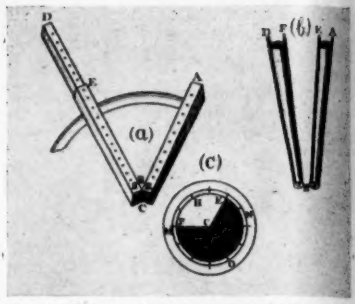


Fig. 5. Bouguer's Lucimeter and Heliometer.

two square-section tubes whose interiors are blackened and provided with suitable diaphragms. The two tubes are joined together at one end by a hinge BC, and have at this end two circular holes S and R covered with thin white paper. The other two ends A and D each have a circular opening, 1 in. in diameter. One of the tubes BD is provided with a telescopic portion, so that its length can be altered and produce the same effect as would be produced by varying the size of the hole at D. Tube CA is about 24 in. long.

In order to compare the brightnesses of two portions of sky the tubes are directed at them and the holes S and R viewed through a larger tube about 7 in. long which more or less surrounds the end BC. An assistant then alters the length of the tube BD until the two holes at S and R appear equally bright. The relative brightnesses of the two portions of sky viewed are then deduced as inversely proportional to the squares of the lengths of the tubes.

This instrument has two limitations: it cannot deal with very small areas, nor can it cover a large range of brightnesses. Bouguer therefore constructed another, which he calls a Heliometer. This is shown in Fig. 5b. This instrument uses the principle that the brightness of an image produced by a lens is proportional to the area of the lens.

The Heliometer consists of two equal convex lenses AE and DF mounted at the ends of two tubes of length about 6 to 7 ft. The ends at B have two small holes covered with paper at the foci of the two lenses.

The instrument is pointed at the sky or sun, and the angle between the two tubes adjusted so that an image of one of the two portions that are to be compared falls on each hole. In order to equalise the brightnesses of these images the aperture of one of the lenses is reduced by means of the adjustable sector shown in Fig 5c, and the fraction of the area used read off on the scale at the circumference. The relative brightness is given as the inverse of the ratio of the areas of the two lenses.

Bouguer points out that the centre of a lens is not as transparent as the periphery, so that variation of aperture by stopping down would not be legitimate. The only method which is free from criticism is one which alters the area but maintains the relative contributions of different zones of the lens the same. This is done by means of the variable radial sector.

With the Lucimeter, Bouguer explored the variation of sky brightness from point to point. He showed that near the sun the brightness is very much higher than at parts remote from the sun, and that very often this variation in brightness is not by any means obvious to the naked eye. He observed several times that "when the air was very serene" the brightness at a point of 8° or 9° from the sun was as much as four times the brightness at 30° from the sun.

He also made observations on the illumination produced by the four quarters of the sky. This he accomplished by placing two white cards at right angles to a wall. The cards faced each other at a distance of a few feet apart. When the sun had just passed behind the wall one of the cards was illuminated by the sky which extended from the sun to 90° from it and the other by the sky from 90° to 180°. He viewed the two surfaces simultaneously by means of the Lucimeter, whose tubes were each directed at the same angle to one of the two white cards.

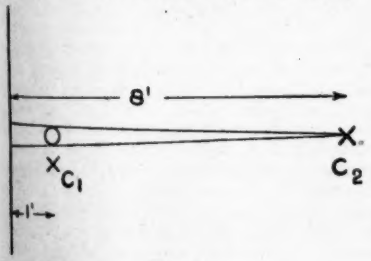


Fig. 6.

He also compared sunlight with that from a quarter of the sky. The results of these daylight experiments are not given in his book, but blanks are left in the text as edited by de la Caille. Bouguer intended completing the experiments in 1759, but his death in 1758 prevented him.

His observations with the Heliometer on the sun's disc showed that its brightness was a maximum at the centre and fell off towards the edge.

Bouguer's interest in photometry was not in photometry itself, but in the information which photometric measurements could afford on a number of problems. He never was interested, so far as can be seen, in the comparison of artificial light sources, nor does he ever mention the desirability of having a standard light source.

He did, however, perform an experiment on the sensitivity of the eye which is of interest to us, as he determined the Fechner fraction at one level of brightness. This he accomplished by setting up a candle at 1 ft. from a white surface. Close to the candle (Fig. 6), and also at a foot from the surface, he placed a vertical rod. He then moved another candle at right angles to the screen until the shadow of the rod was only just visible. He found that the shadow was just visible when the second candle was 8 ft. from the screen. He then concluded that the eye can detect a difference of 1-64th in the brightnesses of two adjacent surfaces since the illumination outside the shadow is 1-64th more than that inside the shadow.

He mentions that this value probably varies from individual to individual and probably for any one person at different parts of the retina. He suggests that objects in a room, viewed through a window from outside, will not be visible if they have a brightness less than 1-64th that of the sky seen by reflection in the window. His measurements were confined to one brightness level, so that he was not able to anticipate Fechner, who

later showed that over a considerable brightness range the fractional difference in brightness which can be observed is a constant, which modern work puts at something less than 1-100th.

Johann Heinrich Lambert, whose work we shall now consider, was born on August 26, 1728, at Mulhausen, in Alsace, Mulhausen then being part of Switzerland. His father was a Frenchman who left France after the revocation of the Edict of Nantes. Lambert had a very meagre education at the school in his native town, which he supplemented by considerable reading, and at the age of fourteen he became a book-keeper at a local iron works, and in his seventeenth year secretary to the editor of a Basel newspaper. The editor recommended him, in 1748, as tutor to the sons of Count von Salis of Coire, who possessed a good library, and this gave Lambert an excellent opportunity of continuing his literary and scientific studies. In 1759, after completing a two years' tour of Europe with his pupils, he settled at Augsburg for a number of years, and later, in 1764, he moved to Berlin. He here became an intimate of Frederick the Great and the group of scholars gathered at Berlin. He became a member of the Berlin Academy of Sciences, and died there on September 25, 1777, at the age of forty-nine.

Lambert was the author of several books and also of numerous papers on scientific and philosophical subjects in the Memoirs of the Berlin Academy. He was responsible for the introduction of hyperbolic functions into mathematical analysis. His particular genius showed itself in his ability to apply mathematics to physical problems. Unfortunately, he lived in an age of great mathematicians, so that, to a considerable extent, he was overshadowed by his brilliant contemporaries, Euler, Lagrange, and Legendre.

His earliest work, which appeared in 1758, was on "Les Proprietés remarquables de la Route de la Lumière par les Airs"—a book which dealt largely with atmospheric refraction. In this he mentions, as did Bouguer, that there are two branches of optics, one dealing with the paths of rays and the other with photometry, which is concerned with the brightness of light, its density, its illuminating force, its degrees, and their increases and diminutions. He refers to Bouguer's essay and promises to produce at a later date an essay on the same subject. This work appeared in 1760 as "Photometria sive de Mensura et Gradibus Lumenis, Colorum et Umbrae."

Lambert's work is very mathematical in character and is written in the form of theorems, with their demonstrations such as we are familiar with

I. H. LAMBERT
ACADEMIAE SCIENTIARVM ELECTORALIS BOICAE, ET SOCIETATIS PHYSICO-MEDICAE BASILIENSIS MEMBRI, REGIAE SOCIETATI SCIENTIARVM GOTTINGENSI COMMERCIO LITERARIO ADSCRIPTI

PHOTOMETRIA

SIVE

DE

MENSVRA ET GRADIBVS

LVMINIS,

COLORVM ET VMBRAE

AUGUSTAE VINDELICORUM,
Sumptibus VIDVAE EBERHARDI KLETT
Typis CHRISTOPHORI PETRI DETLEFFSEN.
MDCCLX.

Fig. 7. Title page of Lambert's Photometria.

in Euclid's Geometry. Interspersed among the theorems are a number of experiments.

The most interesting parts of the book from our point of view are the first, in which he deals with photometric principles, and the third, in which he deals with reflection from matt surfaces. Mr. Trotter, as has been mentioned before, has dealt in considerable detail with this latter portion. In the fourth book Lambert deals with the eye.

Almost at the beginning of the work he says that "it is greatly to be desired that a photometer should be found similar to a thermometer,

which would indicate the intensity of a light source exposed to it." He mentions that the pupil of the eye, by its opening and closing, does act as a kind of indicating photometer, but doubts whether art can copy nature and produce a substance having the same sensitivity as have the rods and cones of the eye, especially for very weak lights.

He points out that in measuring light the eye is the only judge, but its impressions of brightness are affected by the size of the pupil, and that in order to use the eye in the measurement of light it is necessary for it to compare two neighbouring surfaces at the same time. He then formulates the basic principle of photometry that the eye cannot judge the ratio of two brightnesses presented to it, but only their equality. This leads him to a consideration of the means of producing equality, and he formulates three primary notions as follows:—

(1) Two or more candles give more light than one.

(2) An object appears brighter when it is moved nearer to a light.

(3) Light illuminates a surface less when it falls on it acutely.

The second of these is later expanded into the inverse square law which he derives, as did Bouguer, from the fact of rectilinear propagation and geometrical considerations. The third he expands into his cosine law. In Lambert's day it was customary to measure the angle of incidence from the surface and not from the normal, so that in its original form Lambert's law is given as "the normal illumination is to the oblique illumination as the whole sine (i.e., unity) is to the sine of the angle of incidence."

This law Lambert regarded as a consequence of rectilinear propagation and geometry. It is to be noted that the law refers only to the illumination of surfaces; it has nothing to do with the emission of surfaces, which is a property of the surfaces concerned and not of geometry alone. There can, therefore, be no question of Lambert's law failing in any case, as illumination is always proportional to the sine of the angle of incidence. It is true that for a perfectly diffusing surface the emitted radiation per unit area does vary as the sine of the angle of emission, so that when an emitting surface is said erroneously to depart from Lambert's law what is meant is that it is not a perfect diffusing surface.

The experiments described in the book are extremely simple and consist in the comparison of the brightnesses of two white surfaces and by moving a light source bringing them to equality. There is never any suggestion of the use of an instrument—only the crudest of photometric procedures.

Thus Experiment I (Fig. 8), which has been considered by some as illustrating and anticipating the use of Rumford's shadow photometer, is described more or less as follows: "Two candles equally bright are placed at A and illuminate normally the white wall B G F D, and another equally bright candle is placed at K. A narrow plane HI is placed so that the back part of the right-hand wall is in shadow from the candles at A, while the front part is in shadow from the candle at K. The candle at K is moved backwards or forwards until the two parts of the wall are equally bright. It will then be found that the distance of the two candles at A from the wall is $\sqrt{2}$ times the distance of the candles at K, i.e., the relative intensities of the candles at A and K are as 2 is to 1."

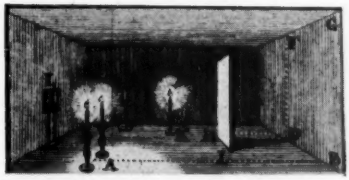


Fig. 8. Illustrating Lambert's experiments with candles to prove the Inverse Square Law.

The illustration shows that this is a very crude arrangement. Later in the book, however, he gives an account of a variant of it in which only one candle is used (Fig. 9). Its light as reflected from one mirror is compared with its light as reflected from two mirrors placed close together, so that the two patches of light produced on a white wall by the reflections from the two mirrors over-

lap. He then moved the single mirror so that the brightness of the patch produced by it had the same brightness as the two superposed patches produced by the two almost coincident mirrors. The wall on which the

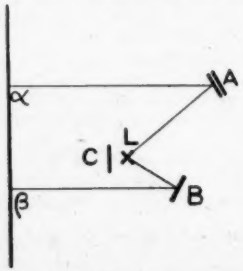


Fig. 9.

patches were received was shaded from the direct light of the candle L by the screen C. Lambert gives results and shows that the mean of five experiments gave as the ratio of the distance LA + Aα to LB + Bβ the value $\sqrt{2}$ to 1 to an accuracy of about 1 per cent. with a spread of 5 per cent.

There is still no suggestion of the use of any instrument, so that it is probably correct to conclude that Lambert did not invent a photometer. He had not, of course, seen Bouguer's "Traité d'Optique," which appeared in the same year as his own work. Otherwise he would not have been able to regret the lack of a photometer.

Like Bouguer, Lambert carried out an interesting experiment on the eye. This consisted of the determination of the variation of the size of the pupil as the illumination on it varied. This he did by measuring its diameter as he stood in a darkened room at various distances from a circular aperture, 4 in. in diameter, in an otherwise opaque window through which a cloudless sky could be seen. The diameter of his pupil was determined by observing it in a mirror and varying the distance of two points on the surface of the mirror so that they coincided with opposite ends of a diameter of the image of the pupil seen in the mirror. Since the image of the pupil is as far behind the mirror as the actual pupil is in front, this distance gave the half diameter of the pupil. He found that at 1 ft. from the aperture his pupil had a diameter of 2.5 mm. which increased asymptotically to about 7 mm. when he was 10 ft. from the aperture. It is probable that Lambert was the first actually to measure the variation of the pupil under different illuminations.

On the whole, however, the book is too mathematical to be usefully discussed in a brief manner. It must be sufficient to state that he made very many calculations on the brightness of images in optical systems and of the illumination due to various surface sources, such as a circular area for points on its axis. He also determined the amount of light received by one circular disc from another parallel and coaxial radiating disc, as well as many others of photometric or astronomical interest.

Benjamin Thompson, Count Rumford, the last of the three eighteenth-century scientists whose work we are considering, was born in Massachusetts on March 26, 1753, of a moderately wealthy farming family. He seems early to have shown considerable scientific ability, for at the age of fourteen he calculated a solar eclipse to within four seconds. He was on the Tory side in our dispute with the American colonies, and so found it convenient, in 1776, when the British evacuated Boston, to come to England. His family connections were such that he soon became the London secretary of the State of Georgia.

His official duties did not, however, prevent him from taking an interest in natural philosophy, so that he was elected a Fellow of the Royal Society in 1779. At the close of the war, after setting out to join the Austrian army and help fight the Turks, he entered the service of the Elector of Bavaria, where he rose rapidly in the service of the State, simultaneously occupying the positions of Minister of War, Chief of Police, and Chamberlain to the Elector, and would later have become Bavarian Ambassador at the Court of St. James but for the law preventing a British subject from representing a foreign Power.

He reorganised the Bavarian army, improved the condition of the working people, and did much to suppress beggars, for whom he provided model homes of industry. In spite of his administrative and courtly duties, he found time to send occasional papers to the Royal Society. In connection with his attitude to science it is interesting to notice that he regarded science, as did Bacon, as a means of increasing man's mastery over his environment and as a means of ameliorating the condition of man. Practically all his work has this inspiration and shows little scientific curiosity for its own sake, which is sometimes regarded as the main source of scientific progress.

This attitude is also shown in his "Proposals for forming by Public Subscription, in the Metropolis of the British Empire, a Public Institution for diffusing the Knowledge and facilitating the General Introduction of Useful Mechanical Inventions and Improvements, and for teaching, by courses of Philosophical Lectures and Experiments, the Application of Science to the Common Purposes of Life." Largely as a result of Rumford's efforts this public institution took form, and in 1800 received from George III. its charter as the Royal Institution.

Fig. 10. Benjamin Thompson, Count Rumford (1753-1814).

Fig. 11. Rumford Monument at Munich.

Rumford left England a short time after this and went to live in Paris, where he contracted an unhappy second marriage with the widow of a distinguished French chemist, Lavoisier, who was guillotined during the Terror. In Paris he continued his philosophical pursuits, which were still directed to the improvement of the comfort of mankind. He died there on August 21, 1814, at the age of sixty-one.

Rumford's interest in photometry and illumination began in Munich about 1789, when, in connection with his model homes of industry, he wished to determine the relative quantities of light produced by different kinds of lamps and candles and the relative expense of lighting rooms in different ways.

In the course of his experiments he devised a method of photometry which he described in a paper presented to the Royal Society in 1794. Rumford's method in its simplest form

was very similar to that described by Lambert, and involved the equalising of the two separate shadows produced on a white screen by a vertical rod about 3 in. in front of the screen. The equalisation was brought about by moving one or other of the two light sources under comparison.

This simple system is the one which is usually described as Rumford's shadow photometer in the text books. As Mr. Trotter has pointed out, this does less than justice to Rumford, who in the same paper described a much more elaborate and improved form of it. Of this, Rumford writes: "I have now brought the instrument to such a degree of perfection that, if I might, without being suspected of affectation, I should dignify it with a name, and call it a *photometer*." This dignity Rumford did not bestow on the earlier model.

The modifications and improvements are described as follows: "The shadows, instead of being thrown upon a paper . . . are now projected upon the . . . back part of a wooden box, . . . open in front . . . and painted black . . . in every part except the back, upon which the white paper is fastened which receives the shadows. . . . I now make use of two cylinders, which being fixed perpendicularly in the bottom of the box . . . when the two lights made use of . . . are properly placed . . . project four shadows upon the white paper . . . which I shall henceforth call the field of the instrument, two of which shadows are in contact precisely in the middle of that field; and it is these alone that are to be attended to . . ." The other two were made to fall on a black mask surrounding the field, and so were invisible. "As the diameters of the shadows vary in some small degree in proportion as the lights are broader or narrower . . . in order to bring these shadows to be of the same diameter which I have found by experience to be advantageous . . . I have rendered the cylinders movable about their axes and have added to each a vertical wing. . . When it is necessary that the diameter of one of the shadows should be increased, the corresponding cylinder is moved about its axis till the wing emerging out of the shadow . . . and intercepting a portion of light brings the shadow . . . to be of the width or diameter required."

This improved photometer and its accessories are illustrated in Figs. 12, 13, 14, and 15. It was symmetrically placed at the junction of two benches, 10 ft. and 20 ft. long, placed 60° apart. Light entered the photometer through two tubes attached to it, and the observer sitting in the angle between the benches, observed through a third opening between the tubes. The lamps under comparison were mounted on adjustable carriages and were moved by means of a winch conveniently situated with respect to the observer, "the sliding motion of the lights being perfectly soft and gentle."

Rumford realised the desirability of having a standard light source of reproducible intensity, as the variations and fluctuations of light sources were the principal sources of difficulty in photometry. He found that an Argand lamp, once properly adjusted, maintained a constant intensity for a longer period than any other lamp. By placing the Argand lamp at 100 in. from the photometer field on one bench and placing at 33 in. on the other, "a cylindric wax candle of known weight and dimensions, which is kept merely for this purpose, being lighted and trimmed and made to burn with the greatest possible brilliancy," he adjusted the wick of the Argand lamp until the photometer indicated equality of the illuminations. In these circumstances the Argand lamp had nine times the intensity of the proof candle.

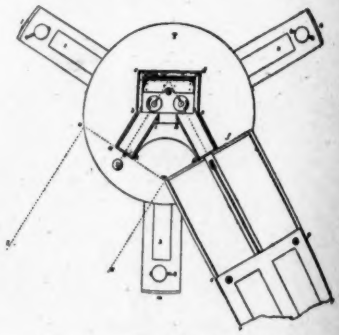


Fig. 12. Rumford's Photometer.

Rumford carried out a very large number of researches with this photometer, some of which we shall mention. He was a very careful experimenter and took very little, if anything, for granted. For instance, realising that the inverse square law only applied if absorption by the air were very small, he carried out experiments on what he calls the "resistance of the air to light."

The results of a number of experiments did not indicate any resistance of the air to light at all. The experiments, if they proved anything, proved the inverse square law to a high degree of accuracy. The subject of atmospheric absorption attracted him greatly, and he suggested Bouguer's method should give information, though from a footnote inserted when his paper was reprinted it appears that in 1794 he was not then acquainted with Bouguer's work.

Rumford was very painstaking in his experiments and also very human, as the following quotation on his method of procedure will show. He writes: "In order that in judging of the equality of the shadows, my mind might be totally unbiased . . . as soon as the shadows appeared to me to be perfectly equal, I gave notice to an assistant to observe, and silently write down, the distance of the lamp or candle, so that I did not even know what that distance was. . . I do not know that any predilection I might have had . . . would have operated so strongly upon my mind and upon my senses as to have made *black* and *white* appear to me otherwise than as they really were, but this I know, that I was very glad to find means to avoid being led into temptation."

Rumford later designed a simpler photometer, which he described in a paper entitled "The Management of Light in Illumination," which he read before the Institute of France in 1811. Fig. 16 illustrates the new photometer, which consists of a wooden block 7 in. x 5 in. x 5 in., on the top surface of which are two vertical rods about 2 in. long and a vertical board fastened to the back of the block and projecting about 3 in. above it. This vertical board which forms the photometer field is covered with white paper on which the shadows of the rods fall. The rods also serve to

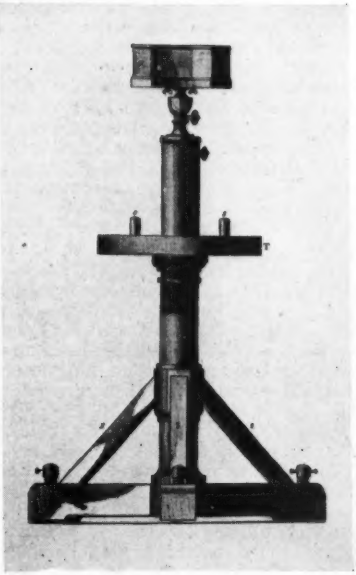


Fig. 13. Rumford's Photometer.

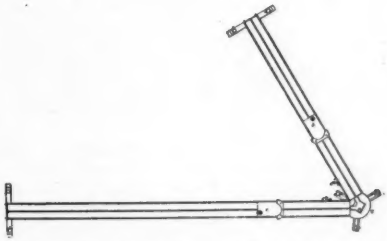


Fig. 14. Rumford's Photometer Bench (plan).

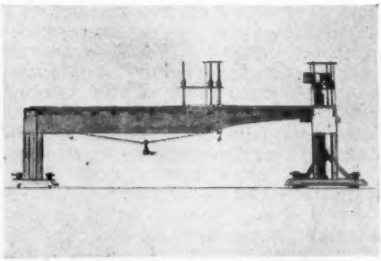


Fig. 15. Rumford's Photometer Bench (elevation).

locate two rulers, each having a circular hole near the end, so that they can be placed over the rods aid serve to measure the distances of the light sources from the photometer. The directions of the rulers are arranged so that lights in the directions of the rulers cast shadows which touch each other at the centre of the photometer field. The rulers are of a type that can be folded like a carpenter's rule, so that the new photometer is very portable.

The rulers are not graduated in feet and inches, but in terms of a "scale of light," which is such that the numbers, which Rumford calls *degrees*, are as the squares of their distances from the middle of the photometer field. The first division is marked 10° and is at a distance of 10 in. That marked 100° is therefore at a distance of 31.62 in.

To fill the important office of a standard Rumford chose "a wax candle of the first quality, just eight-tenths of an English inch in diameter, which, when burning with a clear, steady flame, consumed uniformly 108 grains Troy of wax per hour." To this standard he assigned the value of 100°. It was always placed at the division marked 100° on the ruler, so that the intensity of another source was indicated directly on the other ruler, without computation, when the shadows on the photometer field were equal.

As stated previously, Rumford's interest in photometers was primarily in order to prosecute his researches on the most economic method of lighting the work rooms in his model homes of industry. In his 1794 paper he follows up his description of the photometer with data on various light sources which he obtained with it. For instance, he determined the relative quantities of oil consumed and of light emitted by an Argand lamp and by a lamp of the common construction, and found that for the same quantity of oil consumed the Argand lamp gave 15 per cent. more light. His experiments on an ordinary tallow candle of inferior quality showed that, if after being snuffed its light were represented by 100, after eleven minutes it was 39, after nineteen minutes 23, and after twenty-nine minutes 16. On being

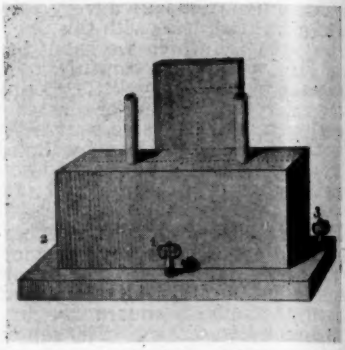


Fig. 16. Rumford's Portable Photometer.

again snuffed it recovered its original intensity of 100.

Other experiments were concerned with the relative quantities of beeswax, tallow, olive oil, etc., consumed in the production of light. Knowing the cost of these materials, he found the cost of producing light from them, and showed that "the light of a wax candle costs just nine times as much at Munich as does the same quantity of light produced by burning rape oil in an Argand lamp."

His interest in illumination lasted until his death in 1814, and led him to write the first treatise on illuminating engineering. This work was the paper previously mentioned on the "Management of Light in Illumination." In this treatise of about 30,000 words he discusses the principles of illumination and describes more experiments of his own.

He points out that as artificial light is used in order that objects may be seen, it is necessary to inquire what circumstances are favourable to distinct vision. He points out also that the illumination is not the only thing to be considered. The importance of shadows in producing distinct vision is mentioned, and he recommends the use of one light source in rooms for those "desirous of having their apartments illuminated at night in the pleasantest manner possible."

He seems to take it as axiomatic that the direct rays from lamps and candles must necessarily fatigue the eyes very much, as they "render it impossible to see distinctly any ob-

ject that may happen to be near these dazzling sources of brightness."

This brings him to the consideration of the advantages of screening light sources used in domestic illumination, a subject which he states has never been properly investigated. He suggests that the flames of lamps and candles should be screened by means of materials, such as ground or etched glass, white stuffs, such as gauze, crape, paper, etc., which disperse the light without destroying it. By surrounding them with such screens, Rumford writes: "All that is ugly and disgusting in a lamp may be concealed; the shadows projected by its solid parts may be obliterated, and the luminous object presented to the view may at the same time be of an elegant form, and have a surface sufficiently large to dispense a great deal of mild light, without being so brilliant as to dazzle and injure the eyes."

Of the advantages of large moderately bright light sources, he writes, "But that kind of illumination which is most favourable to distinct vision is not that which is the most favourable to the beauty of objects in general, or to human beauty. Lines strongly marked are always hard, and some uncertainty is necessary in order that the imagination may have room to play. No decayed beauty ought ever to expose her face to the direct rays of an Argand lamp. . . . That mysterious light which comes from bodies moderately illuminated is certainly most favourable to female beauty, and ought on that account to be preferred by all persons who are wise; but I must not indulge in these pleasing speculations."

One of his first attempts to put his ideas into practice was with the lighting of the lecture and reading rooms of the Royal Institution in 1800. Argand lamps with several burners, suspended from the ceiling or elevated on stands, were covered with large, white gauze screens in the form of a dome or truncated cone so as to conceal the lamps from view. This arrangement met with general approbation from the members of the Institution.

Rumford called his lamps Illuminators, and gave descriptions of three types that answered very well the purpose for which they were designed. In each case they were oil lamps of the Argand type, having an oil reservoir in the form of a hollow, flat ring, connected to burners at the centre of the ring. The screens were dome shaped and consisted of gauze fitted to a skeleton of metal ribs.

The types were as follows:—

The Balloon Illuminator, which was a luminous gauze globe of up to 22 in. in diameter, suspended at a height of 7-8 ft. It had as many as six burners and was intended for use in salons, drawing-rooms, ballrooms, etc. With ornamented chains and with small diamonds of cut-glass along the ribs and supplied with pulleys, they cost, in Paris, about 350 francs.

The Dining Room Illuminator, which was suspended from the ceiling, also served for lighting billiard tables. It had as many as four burners and had an upper, hemispherical dome, round the bottom of which hung a 4-in. frieze of gauze. It could be bought for about 300 francs.

The Table Illuminator had one burner with an upper hemispherical dome. It was mounted on a pillar about 20 in. high, and was used for lighting a dining table when the ceiling height was too small to permit the use of a suspended Dining Room Illuminator. Rumford recommended this Table Illuminator to the studious

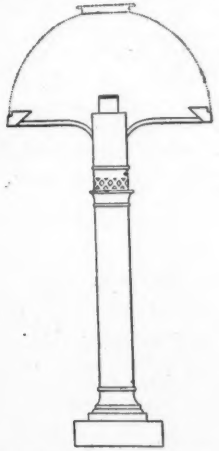


Fig. 17. Rumford's Table Illuminator.

as a reading lamp, as it gave about six times as much light as a good wax candle and illuminated sufficiently, without being too near, and could be placed so that it was not seen by the reader—a circumstance which, he says, "tends much to the preservation of the eyes."

It is illustrated in Fig. 17. Unfortunately it is the only Illuminator of which Rumford gives an illustration. Table Illuminators, mounted on handsome Ionic columns, cost about 60 francs, though there were cheap imitations at 36 francs.

Rumford believed that improvements in illumination depended in a large measure on improvements in the methods employed in the diffusion or, as he called it, the dispersion of light. He therefore discusses at length the properties of various materials and methods for determining their suitability for use as luminous screens for lamps.

Rumford, it will be observed, regarded photometry, not as a branch of pure science, as did Bouguer, nor as of mathematics, as did Lambert, but as the basic science of an art—the art of illumination. In every respect he is entitled to be regarded as the first illuminating engineer.

To conclude this brief survey of the work of these three eighteenth-century contributors to photometry and illuminating engineering, I do not think I can do better than to quote the opening and some later paragraphs of Rumford's essay on the "Management of Light in Illumination."

"The art of illumination," he writes, "although it is undoubtedly one of the most useful that has been invented by man, and contributes more than any other to his comfort and convenience in all countries and in every class of society, has nevertheless been little cultivated; it has not even been considered as an art; for the technical terms have not yet been invented which are indispensably necessary in order to render it possible to treat of it in a clear and satisfactory manner.

"If," continues Rumford, "I have ventured to place *illumination* among the useful arts, if I have taken pains to investigate its scientific principles, and to contrive instruments for facilitating those inquiries which are still necessary to carry it nearer to perfection, I am very far indeed from supposing that it will be in my power to finish that great and important work.

"I shall have done much if I succeed in turning the attention of ingenious men to this interesting subject; and I sincerely hope that the improvements resulting from their united efforts will soon cause all I have proposed to be forgotten."

Since the days of Bouguer, Lambert, and Rumford many technical terms have been invented and many ingenious men have contrived new philosophical instruments. Illuminating engineering has become recognised as one of the most useful of the arts and its cultivation worthy of our modern philosophers. There are, however, many inquiries which are still necessary to carry it nearer to perfection. In the prosecution of these our Society will, I am sure, continue to play an important and honoured part.

I.E.S. Fellowship

The following application for Fellowship has been accepted:—

Wilsdon, John.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form :—"Trans. Illum. Eng. Soc. (London)."

FILTERS TO COLOUR-MATCH TUNGSTEN FILAMENT LAMPS WITH SODIUM-VAPOUR LAMPS

By H. G. W. HARDING
(National Physical Laboratory)

(Communicated)

ABSTRACT

A description is given of the properties of four filters which may be used to measure the luminous intensities of sodium-vapour lamps if tungsten filament lamps are used as intensity standards. In particular, a filter made at the laboratory from Chance OB 2 and OY 1 glasses is described. It enables the measurements to be made under colour-match and approximately energy match conditions. This filter is compared with the Zeiss glass filter used at the laboratory. The spread in the results of six observers is about 2½ per cent. with the Chance glass filter described and about 7 per cent. with the Zeiss glass filter. The mean values of the readings obtained with each of the filters agree to about 2 per cent. The colour, transmission, and temperature coefficients of colour and transmission of the Chance glass filter are given. Other filters which may be suitable for this purpose are Corning 978 with Chance OY 1 glasses or the combination of Wratten 23B and Wratten 57 gelatine filters.

Introduction

To determine the luminous intensity of a sodium-vapour lamp by means of a visual photometer the radiation from the sodium lamp is generally compared with the filtered radiation from a tungsten filament lamp, the angular field size of the photometer being restricted to about two degrees.

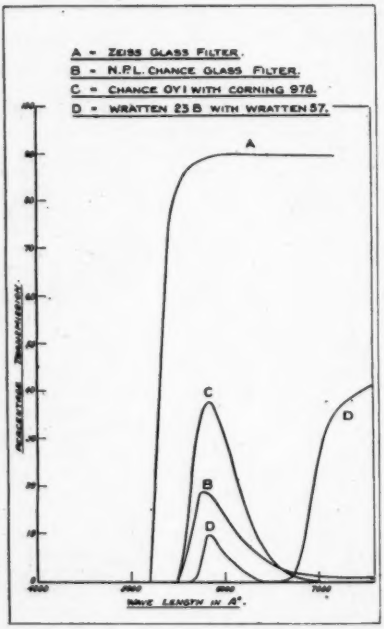
Most of the visible radiation from a sodium lamp is radiation of two wave-lengths, 5890 A° and 5896 A°, and this radiation is compared with that part of the radiation from the tungsten lamp which is transmitted by the filter. If the filter is chosen firstly, so that the radiation from the sodium lamp gives a good colour match with that from the tungsten lamp and filter combination, and secondly, so that there is a good energy match, that is, the spectral transmission of the filter is restricted to the spectral region about 5893 A°, then different observers will agree in their settings when making brightness matches.

The filter previously used at the Laboratory was intended to be used with a tungsten filament lamp at a colour temperature of 2360°K as an illuminant and was made from Zeiss glass, probably OG 1, with the glass thickness adjusted so that the hue-wave-length of the colour of the filter for a 2360°K Planckian illuminant was about 5893 A°. The photopic transmission of the filter for this illuminant is 76 per cent. and the spectral transmission curve is shown as curve A in the figure. When filters of this type are used practically monochromatic radiation is compared with radiation from more than a half of the visible spectrum. The energy differences in the two parts of the photometer field are large, and, whilst a single observer may be able to repeat his own readings, the spread in the readings of six reasonably normal observers may vary as much as 7 per cent. Variations of this order make it necessary to use several observers for every calibration, so that a filter which would enable fewer observers to be employed would be more useful.

A composite filter was made from the Chance Coloured Optical Glasses catalogued as OB 2 and OY 1. With this filter the spread in the readings of the six observers is about 2½ per cent., and with the Zeiss glass the spread is about 7 per cent. The mean values of the readings made with each of the filters agree to about 2 per cent. The angular field size of the photometer used for these measurements was about two degrees. The spectral transmission

curve of this filter is shown as curve B in the figure and the photopic transmission for a 2848°K Planckian illuminant is 8 per cent. Since the transmission of this filter is low it has been designed to be used with a tungsten filament lamp at a colour temperature of 2848°K as an illuminant.

A filter giving a better energy match and having a higher transmission can probably be made if Corning 978 glass is substituted for the Chance OB 2. No supply of this Corning glass was available, so that the Chance



glass was used; but it is proposed to make a filter from the Corning glass when it can be obtained. A Corning Yellow No. 348 could be used to replace the Chance OY 1 but there is likely to be little advantage from this substitution. The probable spectral transmission curve for a filter made from Chance OY 1 and Corning 978, which would give good colour match conditions, is shown as curve C in the figure. The photopic transmission of this filter for a 2848°K Planckian illuminant would be about 16 per cent. The calculations of the colour and transmission of this filter are based on the spectral transmission curve for Corning 978 glass given in the Corning Catalogue and the spectral transmission curve for 3.559 mm. of Chance OY 1 glass given later in Table 1.

A filter stated to be made from the Wratten gelatine filters, numbers 23 B and 57, has been examined but not used at the National Physical Laboratory. The spectral transmission curve of the filter, curve D in the figure, is included as a matter of interest. The photopic transmission is 2.5 per cent. and the transmission for red light is high. The colour of the filter for a 2848°K Planckian illuminant has a hue-wave-length of about 5929 A° which is appreciably different from the required hue-wave-length of 5893 A°. Both the colour and transmission of this filter were calculated from the spectral transmission curve which was measured at the Laboratory.

Production of a Filter from Chance OB 2 and OY 1 glasses

Three properties which can be controlled when making a filter of this kind are the transmission, the colour, and the spectral band of radiation which the filter will transmit. If the glasses are already chosen then a change in one of these properties necessitates a change in the others. Assuming that the thickness of each glass is always adjusted so that there is a colour match between the sodium and tungsten illuminants, then, if the filter has a low transmission, say 1 per cent., the effective radiation transmitted by the filter will be restricted to that of a narrow band of wave-lengths. If the filter has a higher transmission, say 10 per cent., then the effective radiation transmitted by the filter will be extended over a much wider band of wave-lengths because each of the glass components has to be thinned.

The compromise effected for the filter described is that the transmission for a 2848°K Planckian illuminant should be about 7.5 per cent., which means that the spectral transmission is only measurable visually between the wave-lengths 5400 A° and 7700 A°, and that the

transmissions for visible radiation of wave-lengths greater than 7000 A° do not exceed about 1 per cent.

The transmission of the completed filter is about 8 per cent., which is low compared with the 76 per cent. transmission of the Zeiss glass filter. An adequate photometer screen brightness can be obtained, however, if a 500-watt gasfilled projector lamp at a colour temperature of 2848°K (about 1200 H.C.P.) is used for a candle power standard.

To make the filter two plates of glass were polished, the OB 2 to about 1.6 mm. thickness and the OY 1 to about 4 mm. thickness and the spectral transmission of each glass was measured. From the spectral transmission curves the thickness of each glass was calculated, using the "Condensed Tables for Colour Computation" (T. Smith, 1934), so that the colour of the filter for a 2848°K Planckian illuminant had a hue-wave-length of 5893 A° and so that the transmission was about 7.5 per cent. The OY 1 glass was thinned to the calculated thickness and the OB 2 to a thickness about 0.1 mm. in excess of that calculated, then the two filters were cemented together with Canada balsam. The spectral transmission of the composite filter was measured and the colour calculated. The colour was greener than that required, so that a re-calculation of the thickness for the OB 2 glass was made, and the thickness reduced in two stages with a calculation at the end of each so that the OB 2 was not made too thin. It was necessary to separate the two filters in each instance before reducing the thickness of the OB 2 glass. The spectral transmission of each component was determined before the filters were finally cemented together, and the results of these determinations are given in the following Table I. The hue-wave-length corresponding to the colour of the finished filter for a 2848°K Planckian illuminant was 5892.5 A°, and it was not considered necessary to improve this because, when the filter was used to colour match a sodium lamp with a tungsten filament lamp using a photometer having a fifteen degree field, the colour difference between the two parts of the field was barely perceptible. No obvious colour differences have been seen between the radiation from the tungsten filament lamp and filter combination and the sodium vapour lamps which have so far been examined.

Properties of the Filter

(a) Glass Thickness.

The thickness of the Chance OY 1 glass is 3.559 mm. and that of the Chance OB 2 glass 1.217 mm. It is likely that different meltings of glass will require to be worked to thicknesses which are different from these.

(b) Spectral Transmissions.

The spectral transmissions of each component, determined separately before being cemented together, and of the completed filter are given in Table 1. The transmissions for each component are included because these will serve as a useful guide if a filter is to be made from a different melting of glass. No transmission

Table 1.

Wave-length in A°	Percentage Transmission		
	1.217 mm. Chance OB 2	3.559 mm. Chance OY 1	Completed Filter
5400	52.7	0.01	0.007
5500	46.1	1.3	0.68
5600	39.2	15.6	6.77
5700	32.1	44.7	15.84
5800	25.7	66.2	18.74
5900	20.2	75.9	16.87
6000	15.6	80.5	13.81
6100	12.0	82.7	10.89
6200	9.00	83.9	8.32
6300	6.75	84.7	6.30
6400	5.04	84.9	4.72
6500	3.80	85.1	3.57
6600	2.88	85.3	2.71
6700	2.18	85.5	2.06
6800	1.72	85.5	1.62
6900	1.38	85.5	1.30
7000	1.14	85.3	1.07
7100	0.95	85.1	0.89
7200	0.82	84.7	0.77
7300	0.73	84.4	0.68
7400	0.66	84.0	0.61
7500	0.59	83.7	0.55
7600	0.56	83.4	0.52
7700	0.54	83.3	0.50

values are given for visible radiation of wave-lengths shorter than 5400 A° since the OY 1 glass has no measurable transmission over this range of wave-lengths.

(c) Colour and Transmission at 20°C.

The colour and transmission of the filter for each of two Planckian radiators, one at 2848° K and one at 2360°K, are given in Table 2. The value given to the Planck constant C_2 to evaluate the Planckian energy distributions is 14350.

Table 2.

Illuminant	Colour Quality	Hue-wave length in A°	Percentage Transmission
2848°K	0.5707 X + 0.4286 Y + 0.0007 Z	5893	7.97
2360°K	0.5767 X + 0.4226 Y + 0.0007 Z	5903	8.39

The colour of radiation of wave-length 5893 A° is

0.5710 X + 0.4283 Y + 0.0007 Z.

To enable the properties of the filter to be compared with those of other filters that have been mentioned, the colour and transmissions of the filters for various illuminants are given in Table 3.

(d) Temperature Coefficient of Colour and Transmission.

The temperature coefficients of colour and transmission are given in Table 4, and are deduced from the results of calculations made from the spectral transmissions measured with the filter at 20°C. and 30°C.

Acknowledgements

Mr. Pinfold, of the Optics Workshop, made the filter. The photometric measurements to compare the results of luminous intensity determinations, using the filter described and the Zeiss glass filter, were made by Mr. G. C. Cornford, of the Photometry section of the Light Division.

The work described above has been carried out as a part of the research programme of the National Physical Laboratory, and this paper is published by permission of the Director of the Laboratory.

Reference

Smith, T., 1934: "Condensed Tables for Colour Computation." Proc. Phys. Soc., 46, 372.

Table 3.

Filter	Illuminant	Colour Quality	Hue-wave-length in A°	Percentage Transmission
Chance OY 1 with Chance OB 2	2848°K	0.5707 X + 0.4286 Y + 0.0007 Z	5893	7.97
	2360°K	0.5767 X + 0.4226 Y + 0.0007 Z	5903	8.39
Zeiss Glass Filter	2848°K	0.5558 X + 0.4419 Y + 0.0023 Z	5869	72.8
	2360°K	0.5700 X + 0.4280 Y + 0.0020 Z	5893	75.8
Chance OY 1 with Corning 978	2848°K	0.5731 X + 0.4262 Y + 0.0007 Z	5897	15.7
	2360°K	0.5783 X + 0.4210 Y + 0.0007 Z	5905	16.5
Wratten 23 B with Wratten 57	2848°K	0.5915 X + 0.4079 Y + 0.0006 Z	5929	2.48
	2360°K	0.5961 X + 0.4033 Y + 0.0006 Z	5937	2.66

Table 4.

Temperature	Illuminant	Colour Quality	Hue-wave-length in A°	Percentage Transmission
20°C	2848°K	0.5707 X + 0.4286 Y + 0.0007 Z	5893	7.97
30°C	2848°K	0.5744 X + 0.4249 Y + 0.0007 Z	5899	7.68

Sessional Meetings in London

A Joint Meeting with the Science Masters' Association was held at the Imperial College of Science (South Kensington), at 5 p.m., on Tuesday, April 18, when the Chair was taken by the President.

After the Minutes of the last meeting had been taken as read, the President extended a cordial welcome to members of the Science Masters' Association, of whom a considerable number were present. He then called upon Dr. W. D. Wright to deliver an introductory address, reviewing the experiments to be performed.

Dr. Wright then briefly recalled the steps leading to the arrangements of this joint meeting, which it was hoped would serve a double purpose in furnishing members of the Society with a record of useful experiments and in bringing to the notice of science masters some experiments which they might include in their syllabuses.

A series of experiments were then performed on the Production of Light (Mr. L. T. Minchin and Mr. J. B. S. Smyth), the Nature of Light (Mr. J. S. Preston), the Eye (Dr. W. D. Wright), Photometric Principles (Professor J. T. MacGregor-Morris), and the Benefits of Good Lighting (Mr. R. O. Ackerley).

In the ensuing discussion, Dr. J. W. T. Walsh, Mr. E. W. M. Heddle, Mr. G. H. Wilson, Mr. E. G. Savage, Mr. P. Woodland, Mr. C. E. Greenslade, Mr. J. M. Waldram and others took part.

After the various demonstrators had briefly replied to comments on the experiments, a Vote of Thanks to them, to Dr. Wright for his care in making arrangements for the meeting, and to the Imperial College of Science for their hospitality, was proposed by the Chairman, seconded by Mr. W. Ashhurst (Secretary, the Science Masters' Association), and was carried with acclamation.

In conclusion, Mr. Ashhurst also expressed on behalf of the Science Masters' Association, their appreciation of the opportunity afforded of sharing in this joint meeting.

Meetings of Centres and Groups

The eighth Sessional Meeting of the Birmingham Centre was held on May 19, when an address, prepared by Dr. James F. Brailsford (who was unfortunately prevented from attending by a recent accident), entitled "Light as an Aid to Medicine," was read on his behalf by Mr. A. Smith, chairman of the Midland Association of Radiographers.

The address was divided into two parts, the first being Light in Diagnosis, which dealt with the use of various types of instruments used, such as the cystoscope, broncoscope, sigmoidoscope, and ophthalmoscope, followed by a description of the use of infra-red, ultra-violet, and X-rays.

The second part dealt with the use of Light in Treatment, and described the early history of same from the Roman use of the solarium to the modern treatment with light of present-day diseases. A series of slides showing X-ray photographs of various parts of the human anatomy were described, and a full explanation given of the method of diagnosing any abnormality of the internal organs.

An interesting discussion on the address followed. After the discussion Mr. A. J. Pashler, the chairman, introduced to the meeting Mr. E. Stroud, a vice-president of the Society, who happened to be in Birmingham on this occasion and took the opportunity of attending this Sessional Meeting. Mr. Stroud expressed his pleasure at being able to attend. He congratulated the Centre on the excellence of the paper they had just heard and on the evident interest of members in their Centre. There was a great need for co-operation between illuminating engineers and the medical profession.

In conclusion the chairman stated that the annual general meeting of the Centre would take place on June 2, when an address would be given by Mr. J. S. Dow, honorary secretary of the Society.

Additions to List of Members.

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

SUSTAINING MEMBERS:—

George Ellison, Ltd. .....*Representative*: Dr. E. H. Norgrove.
Wellhead Lane Works, Perry Barr, BIRMINGHAM, 22B.

Paisley Corp. Electricity Dept.....*Representative*: Daniel Ross.
27, Blackhall Street, PAISLEY.

CORPORATE MEMBERS:—

Anderson, E. A. .....4, Church Lane, Acklam, MIDDLESBROUGH.
Ansell, B. .....27, Tudor Hill, SUTTON COLDFIELD.
Bamford, C. H.....64, Friar Gate, DERBY.
Buttrey, A. R. .....1, Westborough Drive, HALIFAX.
Dymond, G. W. G.....Leamington Priors Gas Co., Tachbrook Road, LEAMINGTON SPA.
Evans, T. R. .....Rhondda Council Electricity Works, Porth, RHONDDA.
Field, H. V. .....212, Acklam Road South, MIDDLESBROUGH.
Iredale, F. .....Exley House, Exley Bank, HALIFAX.
Leslie, R. K. .....15, Cypress Road, REDCAR.
Levenger, G. E. .....Green Shutters, Danford Lane, SOLIHULL.
Lovett, C. E. .....211, Anglesey Road, BURTON-ON-TRENT.
Manship, L. W.....85, Glenfield Road, LEICESTER.
McAdam, W. Y. .....32, Campbell Street, Hamilton, LANARKSHIRE.
McKerracher, D. .....Physics Department, Technical College, HUDDERSFIELD.
Nicholls, F. ....."Haut Regard," Dene Close, Hayes, KENT.
Ogle, A. J. .....Breckongill, Kenton Bank Foot, NEWCASTLE-ON-TYNE.
Orton, J. .....170, Letchworth Road, LEICESTER.
Parker, W. T. .....113, Station Street, BURTON-ON-TRENT.
Patrick, R. J. .....60, Newlands Road, MIDDLESBROUGH.
Pearce, J. W. .....48, Queen Street, Oadby, LEICESTERSHIRE.
Raisbeck, M. A. .....2, Dorrien Crescent, North Ormesby, MIDDLESBROUGH.
Rose, C. .....89, Grange Road, Ealing, LONDON, W.5.
Sansom, G. H. J. .....The General Electric Company, Ltd., Gunnergate Lane, MARTEN-IN-CLEVELAND.
Scott, W. G. ....."Brierfield," Snape Hill Lane, Dronfield, DERBYSHIRE.
Shepherd, G. E. .....53, Keythorpe Drive, Acklam, MIDDLESBROUGH.
Stabler, H. S. .....310, Coniscliffe Road, Darlington, DURHAM.
Stanyon, F. J. .....48, Eastfield Road, Western Park, LEICESTER.
Underhill, C. H. .....Gas Works, Wetmoor Road, BURTON-ON-TRENT.
Walker, A. ....."Highfield," Ashby Road, Woodville, Nr. BURTON-ON-TRENT.
Weldon, L. M. .....3, Granville Avenue, WEST HARTLEPOOL.
Widdowson, C. E. ....1, Barnsley Road, Edgbaston, 17, BIRMINGHAM.
Wilcock, H. .....100, Devonshire Road, Bolton, LANCASHIRE.
Williams, F. .....41, Cannon Street, Preston, LANCS.

STUDENT:—

Maude, P. H.....66, Crown Street, HALIFAX.

Printed by ARGUS PRESS, LTD., Temple-avenue and Tudor-street, London, E.C.4, England